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(54) Energy recovery from compressor discharge bleed air in gas turbine plants

(57) A gas turbine system that includes a compressor (12), a turbine component (14) and a load (16), wherein fuel and compressor discharge bleed air are supplied to a combustor (20) and gaseous products of combustion are introduced into the turbine component (14) and subsequently exhausted to atmosphere. A compressor discharge bleed air circuit removes bleed air from the compressor (12) and supplies one portion

of the bleed air to the combustor (20) and another portion of the compressor discharge bleed air to an exhaust stack (30) of the turbine component (14) in a single cycle system, or to a heat recovery steam generator in a combined cycle system. In both systems, the bleed air diverted from the combustor may be expanded in an air expander (68) to reduce pressure upstream of the exhaust stack (30) or heat recovery steam generator.

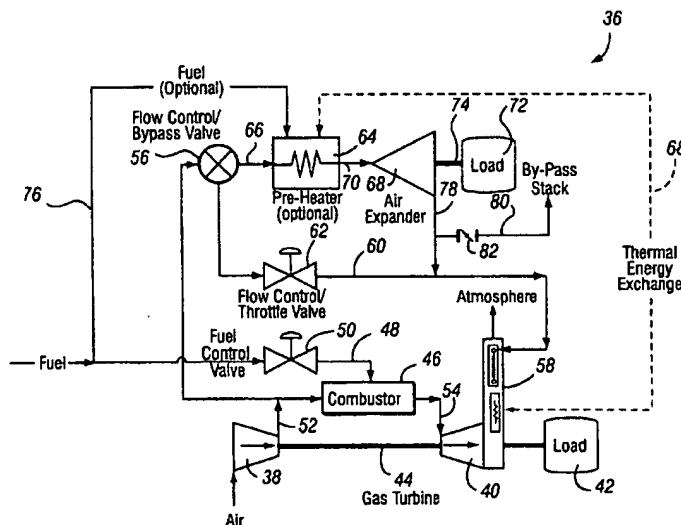


FIG. 1b

Description

[0001] In some gas turbine applications, there are instances of gas turbine plant operation where the gas turbine pressure ratio reaches the operating pressure ratio limit of the compressor, resulting in compressor surge. These instances may arise in applications where low-Btu fuels or any other fuels with large amounts of diluent injection are used, and/or at cold ambient temperature conditions. The compressor pressure ratio is typically larger than the turbine pressure ratio in that the latter is subject to pressure loss in the turbine combustor.

[0002] One common solution that has been used to provide compressor pressure ratio protection is the bleeding off of gas turbine compressor discharge air and recirculating the bleed air back to the compressor inlet. This method of gas turbine operation, known as Inlet Bleed Heat (IBH) Control, raises the inlet temperature of the compressor inlet air by mixing the colder ambient air with the bleed portion of the hot compressor discharge air, thereby reducing the air density and the mass flow to the gas turbine. While this approach eliminates compressor surge, it also reduces turbine output both for the simple cycle operation as well as for combined cycle operation. In the latter case, the reduced gas turbine exhaust flow produces less steam in the Heat Recovery Steam Generator (HRSG) and consequently less steam turbine output. IBH also reduces the thermal efficiency of the gas turbine due to the loss of energy in throttling the compressed air.

[0003] This invention provides an improved compressor bleed air method for providing compressor pressure ratio protection, which results in improved output and efficiency of a simple or combined cycle gas turbine power plant (as compared to the IBH approach). This invention is mostly, but not specifically, applicable to gas turbines utilizing standard diffusion flame combustors.

[0004] Two embodiments are disclosed herein. Each has applicability to both simple and combined cycle systems.

[0005] In a first embodiment, the invention includes bleeding off enough gas turbine compressor discharge air to maintain the compressor pressure ratio limit, and mixing it with the gas turbine (GT) exhaust in a simple cycle system, or at an appropriate location in a combined cycle system (e.g., in the HRSG stack where the two streams have minimum temperature difference). This technique does not increase compressor inlet temperature, and thus does not reduce output as in the case of the IBH approach.

[0006] In a second embodiment, where the compressor bleed function is activated for a large percentage of the gas turbine operating period, the method is similar to that described above, except that it uses an air expander device to recover the excess energy associated with the difference between the compressor air discharge pressure and GT exhaust stack (or HRSG) pressure. In addition to the power output increases, this

method also results in higher power plant efficiency. In this second embodiment, a portion of the compressor discharge bleed air may bypass the expander via a throttling device to combine with the discharge stream from the expander, to thereby enable plant operation during start up, shut down and during the events when the expander is not operating.

[0007] The following are additional optional modifications which may be selected (individually or in an appropriate combination, in both simple and combined cycle operations) based on the economic benefits for a given application. The high pressure bleed air from the compressor is further heated, if required, by means of a pre-heater prior to introduction in the air expander to improve the expander output. The source of this heat can be thermal energy recovered either upstream, such as in the example case of a gasifier with high temperature cooler, or downstream such as the exhaust gas heat recovered from the gas turbine exhaust in a waste heat boiler. Alternatively, the source of heat may include combustion of air and fuel separately supplied to the pre-heater.

[0008] In its broader aspects, therefore, the invention relates to a simple cycle gas turbine system comprising: a compressor, a turbine component and a load, wherein fuel and compressor discharge bleed air are supplied to a combustor and gaseous products of combustion are introduced into the turbine component and subsequently exhausted to atmosphere; and a compressor discharge bleed air circuit that removes bleed air from the compressor and supplies one portion of the bleed air to the combustor and another portion of the bleed air to an exhaust stack of the turbine component.

[0009] The invention will now be described in greater detail, by way of example, with reference to the drawings, in which:-

FIGURE 1 is a schematic diagram of a simple cycle gas turbine with compressor bleed air to an exhaust stack in accordance with the invention;

FIGURE 2 is a schematic diagram of a simple cycle gas turbine with compressor bleed air pressure energy recovery in accordance with the invention;

FIGURE 3 is a schematic diagram of a combined cycle gas turbine with compressor bleed air to a heat recovery steam generator; and

FIGURE 4 is a schematic diagram of a combined cycle gas turbine with compressor bleed air pressure energy recovery.

[0010] With reference to Figure 1, the simple cycle gas turbine system 10 includes a compressor 12, a turbine component 14 and a load (e.g., a generator) 16 arranged on a single rotor or shaft 18. A combustor 20 of the gas turbine receives fuel via stream 22 and control

valve 24, as well as hot discharge air bled off from the compressor 12 via stream 26. Combustion gases are introduced into the turbine component 14 via stream 28.

[0011] During potential compressor surge conditions, a compressor discharge bleed air circuit is utilized. This circuit causes some of the compressor discharge bleed air to bypass the combustor and directs the bleed air directly to the gas turbine exhaust stack 30 via stream 32 and throttle valve 34, the valve 34 also controlling the amount of bleed air introduced into the combustor 20.

[0012] By extracting sufficient compressor discharge bleed air and feeding it directly to the gas turbine exhaust stack 30, the compressor pressure ratio limit is protected while, at the same time, there is no increase in the compressor inlet air temperature, and thus no loss of turbine output.

[0013] In Figure 2, an arrangement is illustrated that is particularly beneficial when the compressor bleed air function is employed for a large percentage of the gas turbine operating period. In this embodiment, the gas turbine system 36 includes a compressor 38, a turbine component 40 and a load (e.g., a generator) 42, arranged on a single rotor or shaft 44. The combustor 46 receives fuel via stream 48 and fuel control valve 50; and compressor discharge bleed air from the compressor 38 via stream 52. Combustion gases are introduced into the turbine component 40 via stream 54. A predetermined percentage of the compressor discharge bleed air is directed to a flow control/bypass valve 56. During potential compressor surge conditions, valve 56 supplies compressor discharge bleed air to an air expander 68 via stream 70, and the air representing the difference between the compressor air discharge pressure and the gas turbine exhaust pressure, is then used to drive a secondary load 72 (e.g., a generator) via shaft 74. Optionally, the valve 56 can adjustably divert the compressor discharge bleed air to the gas turbine exhaust stack 58 via stream 60 and flow control throttle valve 62. This is useful as a bypass scheme (bypassing expander 68) to continue plant operation during start-up, shut-down and other events when the expander is not operating.

[0014] In an alternative arrangement, valve 56 may supply the compressor discharge bleed air to a pre-heater 64 via stream 66. Pre-heater 64 heats the bleed air by heat exchange with turbine exhaust air fed to the pre-heater 64 via stream 76. The heated bleed air is then expanded as described above. The pre-heater 64, optionally, may be fired using fuel separately introduced via stream 78. Excess air from the expander 68 is introduced into stream 60 via stream 80 and then to the gas turbine exhaust stack 58. Some percentage of this excess air may be allowed to bypass the stack 58 and escape to atmosphere upstream of the stack 58 via stream 81 and valve 82.

[0015] Turning now to Figure 3, a combined cycle system 84 includes a gas turbine including a compressor 86, a turbine component 88 and a load (e.g., a generator) 90 arranged on a single shaft 92. Combustor 94 re-

ceives fuel via stream 96 and fuel control valve 98 along with compressor discharge air bled off from the compressor 86 via stream 100. The gas turbine exhaust is supplied via stream 102 to a heat recovery steam generator (HRSG) 104 for reheating steam from a steam turbine 106. Condensed steam from steam turbine 106 is supplied to the HRSG 104 via stream 108 and the reheated steam is returned to the steam turbine via stream 110. Steam turbine 106 drives a second generator 107 via shaft 112.

[0016] During potential compressor surge conditions, a portion of the compressor discharge bleed air is supplied to the HRSG 104 via stream 114 and flow control/throttle valve 116, where it mixes with the gas turbine exhaust before being released to atmosphere via the HRSG exhaust stack 118. As in the embodiment shown in Figure 1, this arrangement does not result in an increase in compressor inlet air temperature, thus allowing the compressor to enjoy the full benefit of low ambient temperatures (or other factors that also produce compressor surge).

[0017] Turning now to Figure 4, an arrangement is shown that is applicable to combined cycle systems and uses an air expander to recover energy associated with the difference between the compressor discharge air pressure and the HRSG pressure. This combined cycle system 120 includes a gas turbine having a compressor 122, a turbine component 124 and a load (e.g., a generator) 126 arranged on a single shaft 128. Combustor 130 receives fuel via stream 132 and fuel control valve 134, along with compressor discharge air bled off from the compressor 122 via stream 136. Combustion gases from the combustor 130 are introduced into the turbine 124 via stream 138. The gas turbine exhaust is supplied via stream 140 to an HRSG 142 for reheating steam from the steam turbine 144. Condensed steam from the steam turbine 144 is supplied to the HRSG 142 via stream 146, and the reheated steam is returned to the steam turbine 144 via stream 148. Steam turbine 144 drives a generator 145.

[0018] During potential compressor surge conditions, a predetermined percentage of the compressor discharge bleed air is directed to a flow control/bypass valve 150 via stream 152. Valve 150 supplies the bleed air to the expander 154 via stream 156. Optionally, the bleed air can first be supplied to a pre-heater 158 via stream 156. The pre-heater 158 heats the compressor discharge bleed air via heat exchange with gas turbine exhaust in the HRSG via stream 160. The pre-heater 158, optionally, may be fired using fuel introduced via stream 162. The heated compressor discharge bleed air is then expanded in the air expander 154 and the excess air is used to drive a third load (e.g., a generator) 164 via shaft 166. During start-up, shut-down or other events when the expander is not operating, the valve 150 may divert the compressor discharge bleed air to the HRSG 142 via stream 166 and flow control/throttle valve 168, thus bypassing the pre-heater 158 and expander 154.

When in service, air from the expander 154 is dumped into the stream 166 upstream of the HRSG 142, via stream 170. It is eventually exhausted to atmosphere through the HRSG stack 172. Some percentage of this air may bypass the HRSG 142 and escape to atmosphere via stream 174 and valve 176.

[0019] It is significant that the compressor discharge bleed air circuits described above are useful under conditions that lead to compressor surge, i.e., low ambient air temperatures; excess flow to the turbine; use of fuels with low heat content, etc. By channeling the compressor bleed air downstream of the compressor, there is no increase in compressor inlet temperature and attendant loss of input as with the IBH approach. With higher ambient temperatures, flow is reduced and there is typically no danger of compressor surge, so that the bleed air techniques of this invention are not required.

[0020] For the sake of good order, various aspects of the invention are set out in the following clauses:-

1. A simple cycle gas turbine system comprising: a compressor, a turbine component and a load, wherein fuel and compressor discharge bleed air are supplied to a combustor and gaseous products of combustion are introduced into the turbine component and subsequently exhausted to atmosphere; and a compressor discharge bleed air circuit that removes bleed air from the compressor and supplies one portion of the bleed air to the combustor and another portion of the bleed air to an exhaust stack of the turbine component.

2. The system of clause 1 including a throttle valve for controlling flow of the bleed air to the exhaust stack.

3. The system of clause 1 wherein said compressor, turbine component and load are on a single shaft.

4. The system of clause 1 wherein said compressor discharge bleed air circuit includes a flow control/bypass valve enabled to divert said another portion of the bleed air to an expander.

5. The system of clause 4 wherein said another portion of the bleed air is introduced into a pre-heater upstream of said expander.

6. The system of clause 4 wherein said another portion of the bleed air discharged from said expander is introduced into said exhaust stack.

7. The system of clause 4 wherein said another portion of the bleed air is bypassed around the expander to enable turbine operation during start-up and shut-down.

8. A combined cycle system comprising a compres-

sor, a gas turbine component, a first load, a heat recovery steam generator and a steam turbine; wherein fuel and compressor discharge bleed air are supplied to a combustor and gaseous products of combustion are introduced into the gas turbine component and subsequently exhausted to said heat recovery steam generator for re-heating condensed steam from said steam turbine and returning the reheated steam to said steam turbine for driving a second load; and a compressor discharge bleed air circuit that supplies one portion of the bleed air to the combustor and another portion of the bleed air to the heat recovery steam generator.

9. The system of clause 8 including a throttle valve for controlling flow of bleed air to the heat recovery steam generator.

10. The system of clause 8 wherein said compressor, turbine component and load are arranged on a single shaft.

11. The system of clause 8 wherein said compressor discharge bleed air circuit includes a flow control/bypass valve enabled to divert bleed air to an expander upstream of said exhaust stack.

12. The system of clause 11 wherein the bleed air is introduced into a pre-heater upstream of said expander.

13. The system of clause 12 wherein bleed air discharged from said expander is introduced into an exhaust stack of said heat recovery steam generator.

14. A gas turbine operating system comprising a compressor, a turbine component and a load wherein fuel and compressor discharge bleed air are supplied to a combustor and gaseous products of combustion are introduced into the turbine component; and a compressor discharge bleed air circuit comprising means for avoiding compressor surge under low ambient temperature conditions without increasing compressor inlet air temperature.

15. A method of avoiding compressor surge under low ambient temperature conditions in a gas turbine operating system that includes a compressor, a turbine component and a load, the method comprising:

- a. bleeding discharge air from the compressor and supplying a portion of the bleed air to a combustor of the gas turbine; and
- b. supplying another portion of the bleed air to an exhaust stack of the turbine component to thereby avoid compressor surge without in-

creasing compressor inlet air temperature.

16. The method of clause 15 including, prior to step b., supplying said another portion of the bleed air to an expander upstream of said exhaust stack.

17. The method of clause 16 including bypassing the bleed air around the expander during startup and shut down.

18. The method of clause 16 including using a portion of the air exiting the expander to drive another load.

19. A method of avoiding compressor surge under low ambient temperature conditions in a combined cycle gas turbine operating system that includes a compressor, a turbine component, a generator, a heat recovery steam generator and a steam turbine wherein exhaust from the gas turbine component is used to reheat condensed steam from the steam turbine in the heat recovery steam generator, the method comprising:

- a. bleeding discharge air from the compressor and supplying a portion of the bleed air to a combustor of the gas turbine; and
- b. supplying another portion of the bleed air to the heat recovery steam generator to thereby avoid compressor surge without increasing compressor inlet air temperature.

20. The method of clause 19 including, prior to step b., supplying said another portion of the bleed air to an expander upstream of said heat recovery steam generator.

21. The method of clause 20 including bypassing the bleed air around the expander during startup and shut down.

22. The method of clause 19 including using a portion of the air exiting the expander to drive another load.

Claims

1. A simple cycle gas turbine system comprising: a compressor (12), a turbine component (14) and a load (16), wherein fuel and compressor discharge bleed air are supplied to a combustor (20) and gaseous products of combustion are introduced into the turbine component (14) and subsequently exhausted to atmosphere; and a compressor discharge bleed air circuit that removes bleed air from the compressor (12) and supplies one portion of the bleed air to the combustor (20) and another portion

of the bleed air to an exhaust stack (30) of the turbine component (14).

2. The system of claim 1 including a throttle valve (34) for controlling flow of the bleed air to the exhaust stack (30).

3. The system of claim 1 or 2 wherein said compressor, turbine component (14) and load (16) are on a single shaft (18).

4. The system of claim 1, 2 or 3 wherein said compressor discharge bleed air circuit includes a flow control/bypass valve (56) enabled to divert said another portion of the bleed air to an expander (68).

5. The system of claim 4 wherein said another portion of the bleed air is introduced into a pre-heater (64) upstream of said expander (68).

6. The system of claim 4 or 5 wherein said another portion of the bleed air discharged from said expander is introduced into said exhaust stack (58).

7. The system of claim 4 wherein said another portion of the bleed air is bypassed around the expander (68) to enable turbine operation during start-up and shut-down.

8. A method of avoiding compressor surge under low ambient temperature conditions in a gas turbine operating system that includes a compressor (12), a turbine component (14) and a load (16), the method comprising:

- a. bleeding discharge air from the compressor (12) and supplying a portion of the bleed air to a combustor (20) of the gas turbine; and
- b. supplying another portion of the bleed air to an exhaust stack (30) of the turbine component (14) to thereby avoid compressor surge without increasing compressor inlet air temperature

9. The method of claim 8 including, prior to step b., supplying said another portion of the bleed air to an expander (68) upstream of said exhaust stack (30).

10. The method of claim 8 or 9 including bypassing the bleed air around the expander (68) during startup and shut down.

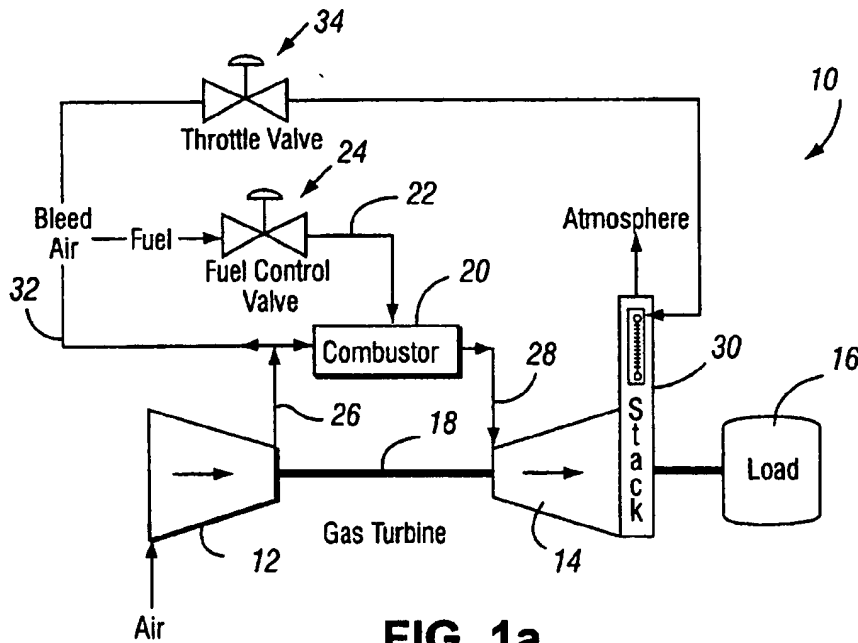


FIG. 1a

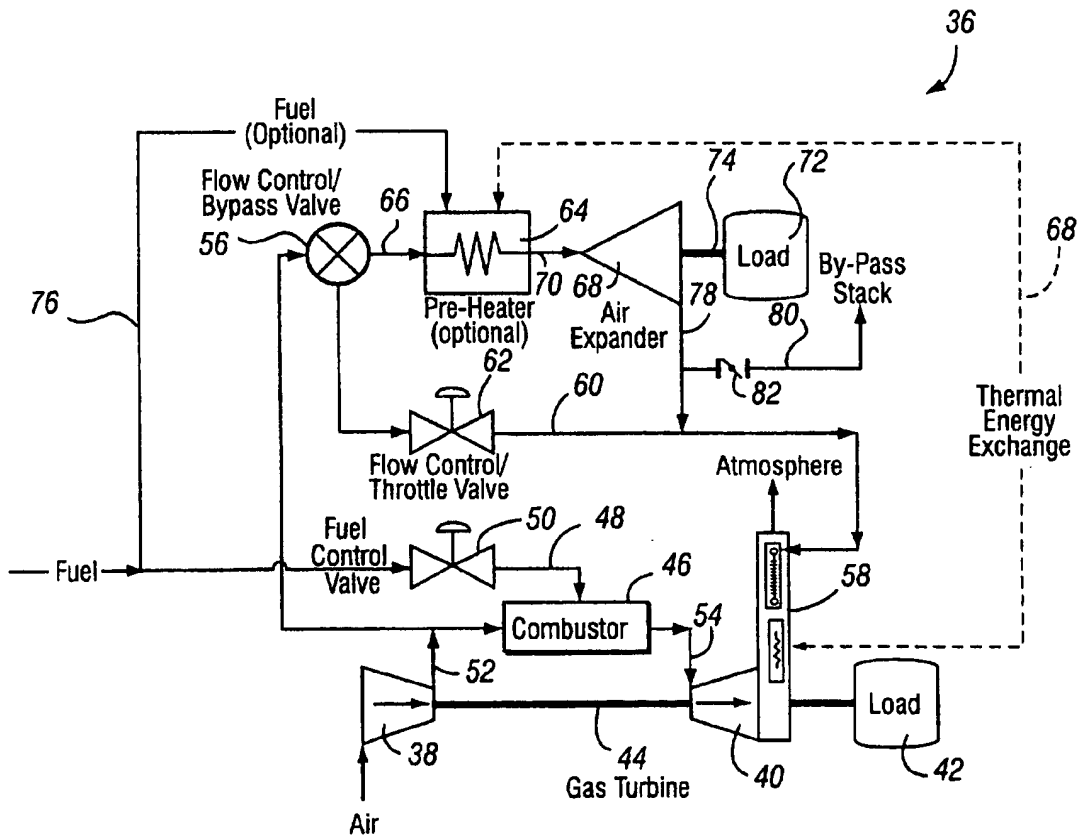


FIG. 1b

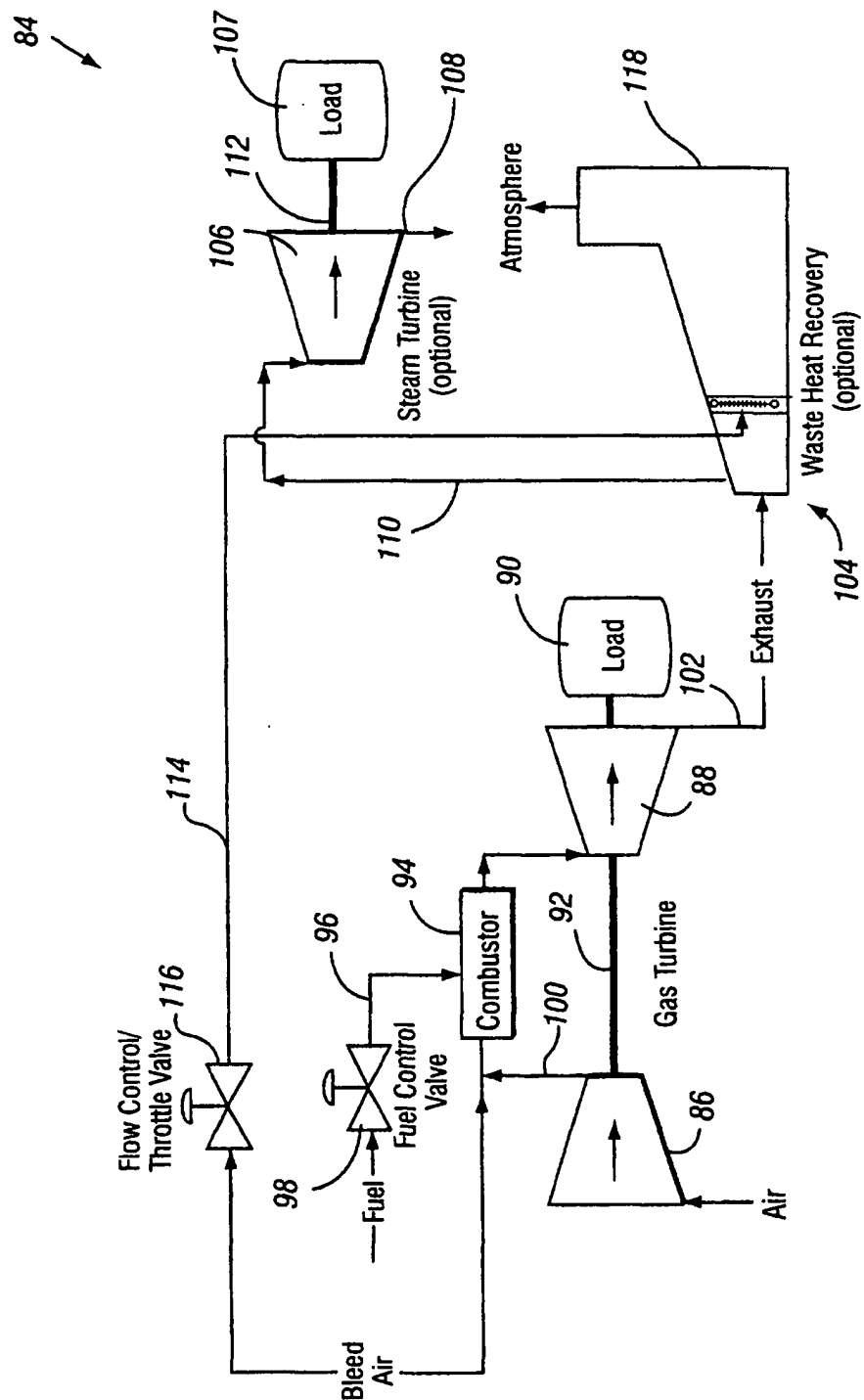


FIG. 2a

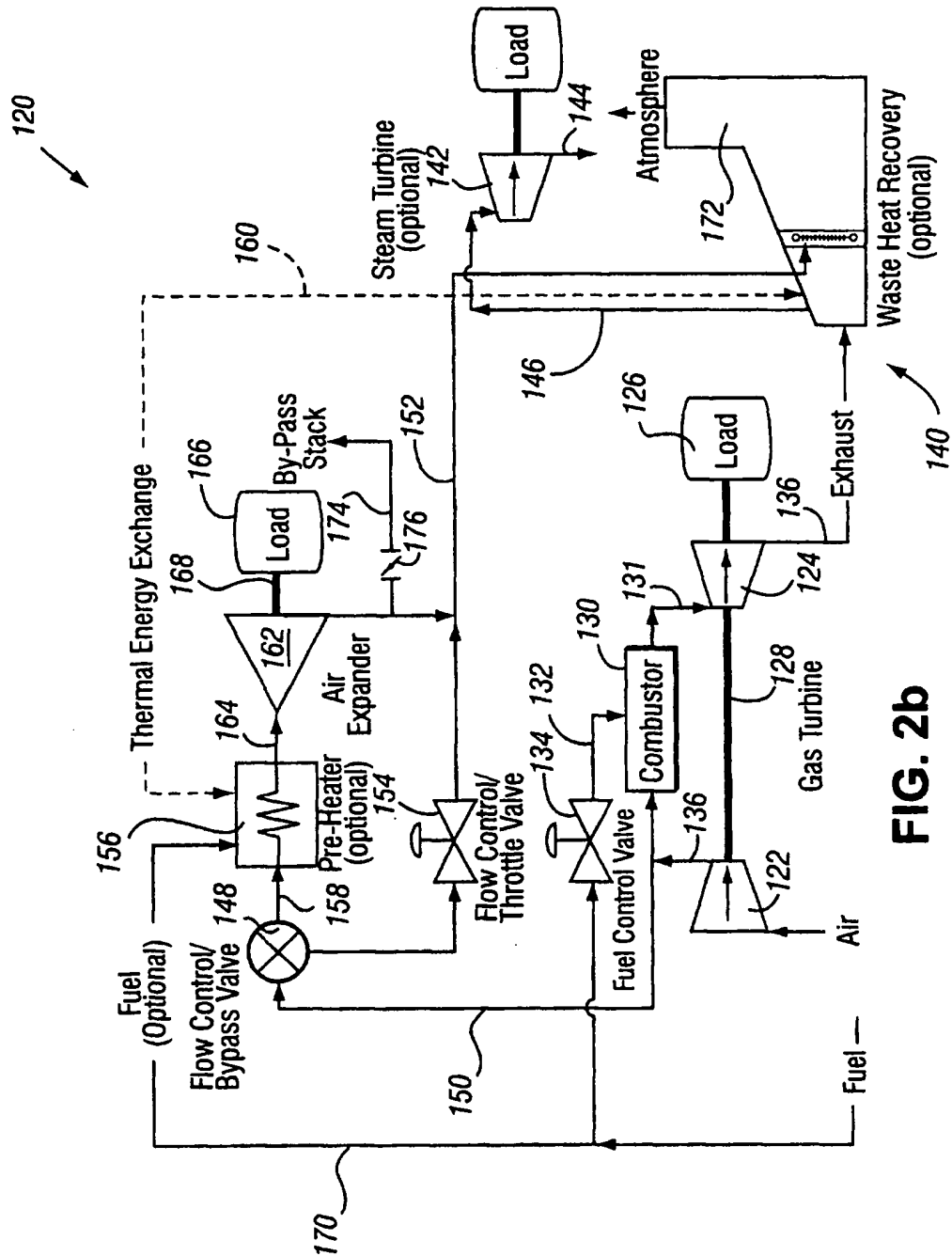


FIG. 2b

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